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The Experiment Research of the Powder Jetting Performance for the South Africa HS Active Explosion Suppression System

Wang Jun-feng[a]*, Wu Jian-ming[a], Yu sheng[b], Helmuth Spath[b]

[a]College of Mining Engineering, Taiyuan University of Technology, Taiyuan 030024, China
[b]Shanxi Lanhua HS Suppression System Co.,t Lt., Jincheng , 048000, China

Abstract

The powder jetting performance and the jetting rate were analyzed, and the jetting pressure was studied under different amount of explosion suppressant agent, different length and number of high pressure nozzles as well. The technical parameters of active explosion suppression system were tested and verified. The results showed that the suppression barrier forming rate was 0.024m/ms, the roadway of 6.25m^2 section area could be filled in 100ms after the system was triggered. The longer the side distance was, the quicker the jetting pressure released. The formulation was obtained to calculate the amount of explosion suppressant agent for the unit area. The jetting rate was higher than 90% which can enssure a satisfied explosion suppression effect.

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Keywords: gas; active explosion suppression; powder jetting performance; suppression barrier; jetting rate

1. Introduction

Coalmine methane control is always the most important aspect for the mine safety. In China, more than 70% of the coalmine major accidents are related to the methane.[1,2] The coalmine methane disaster is more serious these years along with the application of the bigger mining scale, deeper mining depth and integrative technique for production. It is urgent to be solved for the coalmine safety. Normally there are two kinds of methods to control coalmine methane explosion. First, it is to prevent the forming of the explosion triangle; second, to use the effective explosion suppression facility to stop the explosion spreading so that to reduce the loss of lives and property.[3] Traditionally in China, the rock powder shed or the water curtain were employed underground as explosion suppression methods. Yet the impact is not as good as expected since the ventilation evaporation, coal dust pollution or the humidity agglomeration.

Many countries such as England, Germany and Russia, who owns the advanced technology on coalmining field, did plenty of research work on the active explosion suppression (AES) technology. They developed kinds of explosion suppression equipment to control the explosion flame by rapid jetting. Although similar researches were taken in China in recent year, it is not widely utilized because of the technical reason.

The South Africa active explosion suppression system was developed by Mr. Helmuth Spath and it owns the world-class patent. It applied the military technology to the civil use. The system had been appointed as the compulsory equipment for coalmines by the Mining Energy Department of South Africa since it successfully suppressed several methane explosive accident.[4] Currently, series of HS system have been extensive used not only in

[a] * Corresponding author. *Tel.: +86-351-6187815; fax: +86-351-6040552.*
E-mail address: tyutwjf@163.com

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South Africa, but also in Spain, America, Egypt, Australia and Turkey etc. But in China, it was just introduced into one or two coalmine since 2006. The system can be separated into three categories: the machine-carry type, the shield type and the roadway type. It can effectively suppress the extension of methane and/or coal dust explosion through the active detection, rapid response and automatic extinguishment. It makes up the deficiency of the negative explosion isolation system, and, it can establish the solid defense for the coalmines to reduce the methane explosive disaster in China.

To extend the utilization of the HS AES system in China, the technical parameters for underground utilization must be defined. This is the key issue. For this purpose, the research team carried on a test to study the powder jetting characters of the HS AES system at the Hense test base of Shanxi Lanhua Group. The research included the pressure-time relationship during the jetting period of explosion suppression agent after the system was triggered. The test can also obtain the jetting rate of the HS system by comparing the quantity of the agent before and after the jetting action.

1. South Africa HS Methane AES technique

The theory of the HS AES system: the flame sensor installed on the system detects the methane explosion or the coal dust combustion immediately when it happens, then the flame signal turns into a digital signal to be transferred within the system. After this digital signal is verified, the high pressure vessel is triggered by the order from the control box. Then the explosion suppressive agent in the container is released in an extreme short time and forms a physical barrier to stop the flame spreading, so that to reduce the accident impact area and the forming of the harmful gas. Consequently, the underground coalmine and the workers' life are safe from the dangerous.[5,6] Fig. 1 shows the schematic diagram of the HS AES system. Fig. 2 shows the structure map.

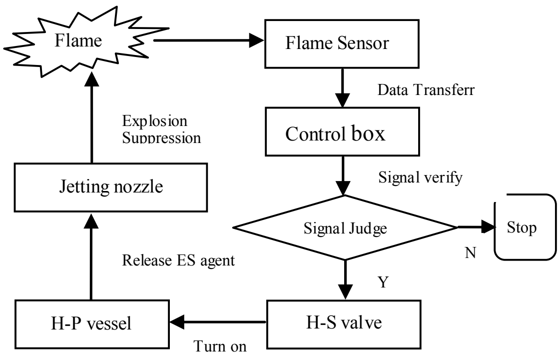
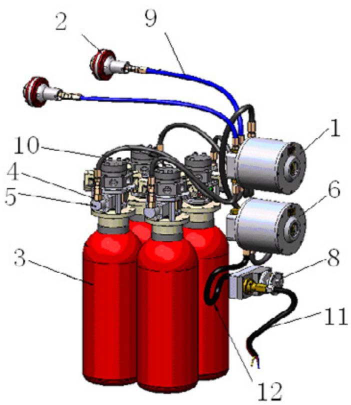


Fig. 1. The Schematic Diagram of the HS AES system



1-Control box; 2-Flame sensor; 3-High-pressure vessel; 4-High speed valve; 5-Starter; 6-Power box; 7-Release nozzle; 8-Lock switch; 9-Cable for flame sensor; 10-Cable for high pressure vessel; 11-cable for main input; 12-Cable for power box

Fig. 2. The Structure Map of HS AES System

2. Test Research

Two separated tests were carried on for the jetting performance of the HS AES system. The first one was the performance analysis test for the jetting powder pressure (sign test A hereinafter). The second was the effect of the jetting powder test (sign test B hereinafter). At last, compared the quantity of the jetting powder inside of the vessel before and after the action (sign test C hereinafter). The following describes the devices, process and the analysis of the experiment. Fig. 3 shows the schematic diagram of the jetting performance test for the AES system. The major devices includes high-pressure vessel, high-pressure jetting tube, pressure data collector, ES agent releasing room, oscillograph and computer etc.

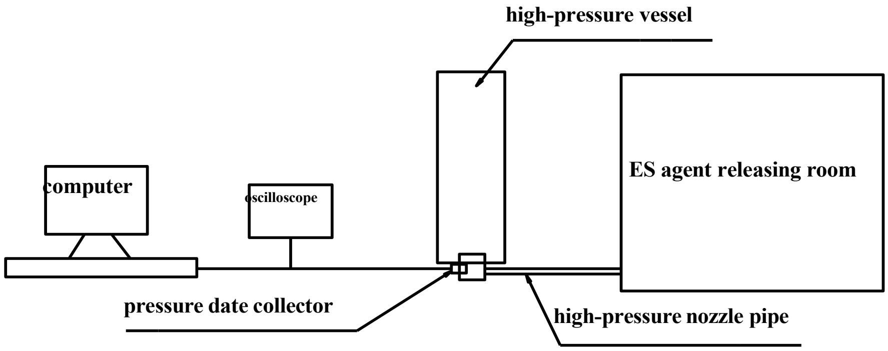


Fig. 3. The schematic diagram of the performance test for the ES system

2.1. Pressure performance test of the jetting powder (Test A)

2.1.1. Test purpose

The test was trying to get the jetting parameters under the same pressure with different quantity of the ES agent, different quantity and different length of the high-pressure tubes, therefore to get the effective amount of the extinguish media as barrier forming material.

2.1.2 Test devices

The test devices were composed by the high-pressure vessel module, high-pressure jetting tube, pressure data collector, ES agent release room, oscillograph, computers etc. Please refer to Fig. 4 to Fig. 6.

Fig. 4. High-pressure modules and the ES agent release room

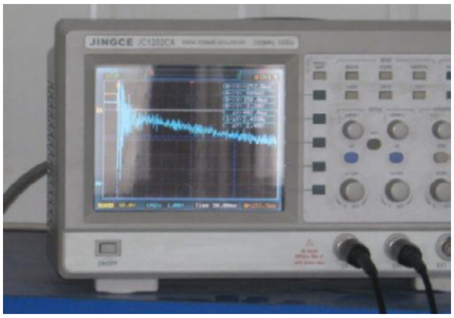


Fig. 5. Oscillograph

Fig. 6. Pressure data collector

2.1.3 Test process

(1) Filled the high-pressure vessel module with full pressure; connected it to the ES agent release room through high-pressure jetting tube; installed the pressure data collector to the high-pressure valve of the vessel module; used the cable to connect the pressure data collector to the oscillograph and the computer; (2) Turn on and verify the testing devices; (3) Triggered the system to spray the ES agent; (4) Caught and recorded the pressure date; (5) collected and weighed the remain ES agent after jetting; (6) followed the above consequences, did the other test based on the Table 1 states.

Table 1. the test conditions for the pressure performance testing of the ES agent

Test No.	ES agent amount	Pressure in vessel	Tube nozzle	Tube length
1	8kg	10MPa	0/1	-
2	8kg	10MPa	2	2m
3	8kg	10MPa	2/1	2m
4	15kg	10MPa	2	2m
5	15kg	10MPa	3	2m
6	15kg	10MPa	1-4	2m
7	20kg	10MPa	3	2m
8	20kg	10MPa	2	2m
9	20kg	10MPa	1	2m
			1	3m
10	20kg	10MPa	2	2m
			3	2m

2.1.4 Result Analysis

According to the experiment, the release of the ES agent was impacted by the hole diameter, hole amount, and the tube length. The test was carried on under the same pressure with 8kg, 15kg, 20kg ES agent and all the data had been analyzed. The following diagrams are the analysis based on the 20kg amount of ES agent. Please refer to the diagram from Fig. 7. to Fig. 8.

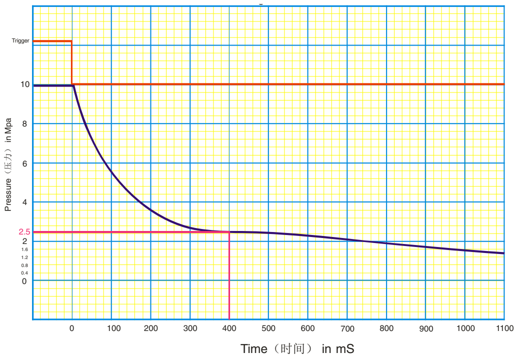


Fig. 7. The jetting diagram with 3×2m tubes (20kg)

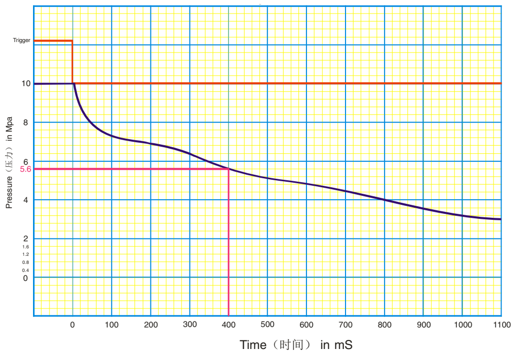


Fig. 8. The jetting diagram with 2×2m tubes (20kg)

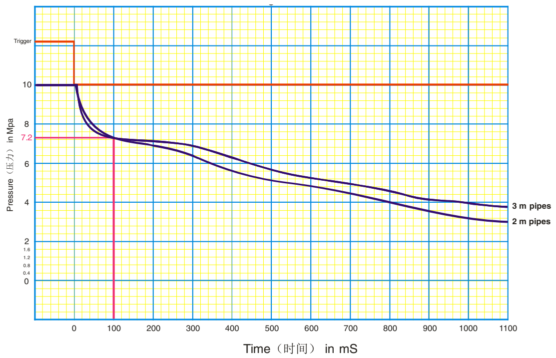


Fig. 9. The jetting diagram of 2m and 3m tubes

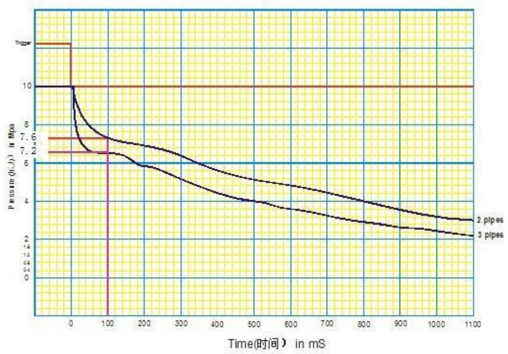


Fig. 10. The jetting diagram with 2×2m and 3×2m tubes

Here we assumed the jetting powder flowed along the ideal liquid steady flow. According to the Euler equilibrium differential equation:

$$\frac{\partial p}{\partial x}dx+\frac{\partial p}{\partial y}dy+\frac{\partial p}{\partial z}dz=\rho(Xdx+Ydy+Zdz)$$

And $p=p(x,y,z)$

So
$$dp=\frac{\partial p}{\partial x}dx+\frac{\partial p}{\partial y}dy+\frac{\partial p}{\partial z}dz$$
$$dp=\rho(Xdx+Ydy+Zdz)$$

Assumed the powder from the nozzles flowed as linearity tube of flux: the formulation could be simple as:

$$dp=\rho(Xdx+Ydy)$$
$$p_0-p=\int_0^s \rho d(s) \qquad \text{(Eq. 1)}$$

where p—ES powder pressure at the outlet, MPa;
p_0—initial pressure, MPa;
ρ — ES powder density, kg/m^3;
s—Jetting tube area,m^2

From the Fig. 7, 8 and the Eq. 1 can get: 20kg ES agent under 10MPa pressure, three tubes' area S_1= 3×283.3mm^2= 850.15 mm^2, two tubes' area S_2= 2×283.3 mm^2=601.01 mm^2. Suppose that the viscosity loss at the tube end is same, obviously that the pressure with three tubes drops rapidly. At the time of 400ms, the pressure with two tubes is 5.6MPa and the pressure with three tubes is 2.5MPa. Both of the pressures reduce along with the rule of second power index. The side distance can be deduced based on the tube area: 2.25m for single-tube side distance, 1.75m for the double-tube side distance and 1.25m for the three-tube side distance. It means that the longer the side distance is, the quicker the pressure loss.

Fig. 9 shows that 20kg ES agent with the 10MPa pressure, the on-way resistance of 2m tube is less than that of 3m tube, smaller viscosity loss and rapid pressure loss. Yet when the time goes to 100ms, the pressure curve shows a point of tangency for 2m tube and 3m tube, both are 7.2Mpa.

From the above we can get that during the time 0-100ms, the pressure droppeds rapidly. After 100ms, the pressure was declining smoothly. For the system with two tubes, the pressure dropped to 7.6MPa after 100ms, 3Mpa after 1100ms and the jetting was still going on. For the system with three tubes, the pressure of the high-pressure vessel dropped to 7.2Mpa after 100ms; it became 2.1MPa after 1100ms and the jetting was still going on. These two cases both met the jetting requirement.

The test showed that the minimum quantity of the ES agent should be above 7kg/ m^2.

2.2 Jetting effect test (Test B)

2.2.1 Test purpose

The test studied the H-DV jetting video made by high-speed Videocon (1000frm/s) to verify the reliability of the technical parameters. Therefore to get the time of barrier forming for unit area and the speed of barrier forming. Furthermore, to study how much the roadway section area is suitable to the different roadway type systems.

2.2.2 Experiment devices

The major devices for the test is the CH4-2 AES system, 2.5m×2.5m powder jetting shed, high-speed DV, CH4 explosion trigger etc. Fig. 11 shows the real picture of the test devices.

Fig. 11. Powder jetting effect test picture

2.2.3 Powder jetting effect test process

(1)Put the CH4-2 AES system in the 2.5m×2.5m shed, put CH_4 explosion trigger in front of the sensor, High-speed DV outside of the shed, recorded the process through the window；(2)Ignited the CH_4 and trigger the jetting system;(3)turned on the High-speed VD; (4)Settled and studied the H-DV video information.

2.2.4 The analysis of the test result

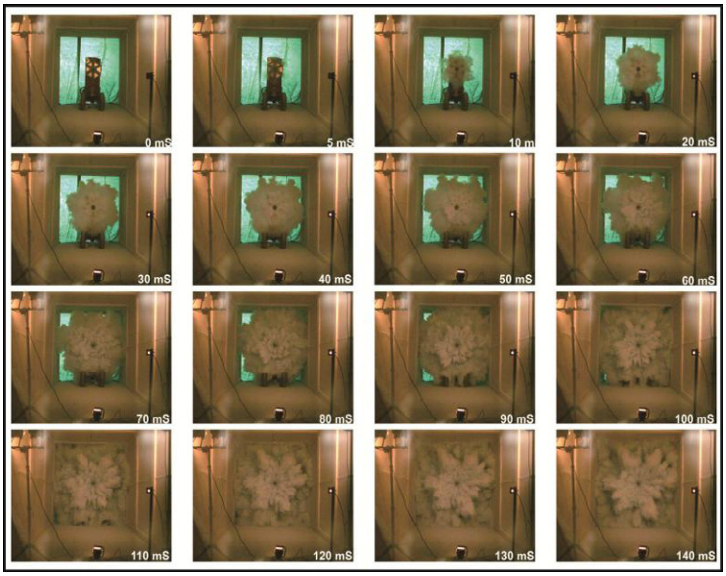


Fig. 12. The pictures of the ES barrier forming

From Fig. 12, it can tell that the CH4-2 AES system can form a barrier with 2.4m thickness in 100ms after explosion and it can fill the 6.25m^2 roadway completely. That means the barrier can be formed with the speed of 0.024m/ms. Combine the result from the Test A that the pressure in the high-pressure vessel kept at 7.2MPa level and it changed to 3MPa after 1100ms while the jetting was still going on.

In order to get the typical curve of the speed of the CH_4 explosion spreading, the research team did the experiment simulating roadway at Kloppersbos explosion center in South Africa. The test showed that ignited 36m^3 CH_4 with 9% concentrate in a 4.9m^2 roadway with 200m length, the detected average speed was 160m/s at the 30m distance to the fire ignition. Please see Fig. 13.

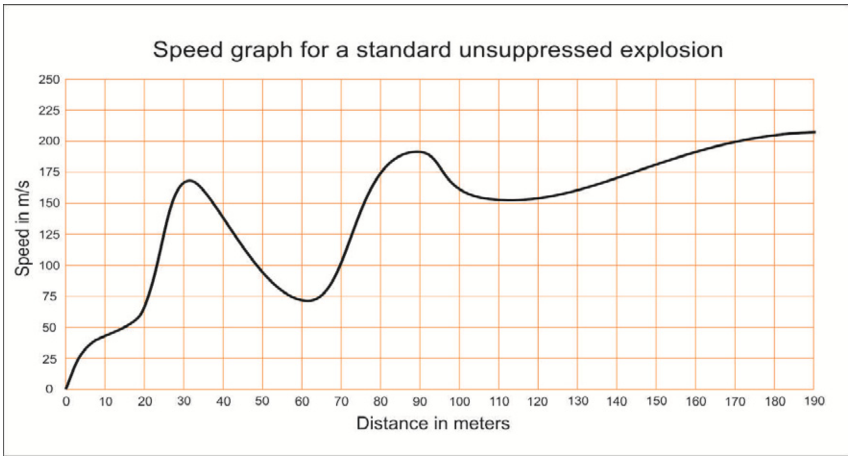


Fig. 13. Curve of the explosion spreading speed

If the roadway section area is 3×3m, according to the explosion spreading curve, the flame speed will be reduced to 96m/s with the same methane explosion.

From all the above can get the conclusion:

The roadway barrier type 4×2 (three tubes) is suitable for the section area of 2.75×2.75m^2.
The roadway barrier type 6×2 (two tubes) is suitable for the section area of 4.2×3.2m^2.

2.3 Jetting rate test (Test C)

This test was not an individual one. It was carried on at the same time with test A and test B. When the test A and test B were completed, weighed the remain inertia phosphate in the vessel and calculated the jetting rate by:

$$\eta = \frac{m_0 - m_1}{m_0} \times 100\%$$

For the case of 20kg ES agent, the remain agent was 0.45kg and the jetting rate is: (20-0.45)/20=97.75%.

3. Determine the ES agent amount for the unit area

The ES agent amount should be calculated by the roadway section area, normally not less than 7kg/m^2. Considering together with the location of the system, the minimum ES agent amount could be adjusted by the following equivalent:

$$Q=7\times V\times K_1\times K_2L \quad \text{(Eq. 2)}$$

where Q— ES agent amount
V— Roadway section area
K_1— defense distance adjust coefficient
K_2—Jetting angle adjust coefficient.

Educe the ES agent amount for the unit area:
Q'=Q/V=$7\times K_1\times K_2L$ (K_1, K_2 definition refer to Table 2)

Table 2 Definition for $K_1$and K_2

Distance		3-10m	10-30m	30-60m	60-100m	100-120m
Defense distance adjust coefficient K1		1	1.25	1.4	2.2	2.8
Jetting angle adjust coefficient (angle with the vertical direction) K2	0º	1	1	1	1	1
	15º	1.1	1.1	1.2	1.2	1.2
	30º	1.2	1.2	1.32	1.32	1.32
	45º	1.4	1.4	1.8	2	2.2

4 Conclusion

The experiment of the jetting pressure performance for the AES system showed that with 20kg ES agent and 10MPa pressure, the pressure with three tubes reduced quicker than the two tubes system. That means longer the side distance was, quicker the pressure lost. When the tube amount were same, the longer the tube was, the slower the pressure lost. Contrariwise, the quicker the pressure lost.

After the ES system was ignited, the pressure in the vessel dropped rapidly during the first 100ms, after that, the pressure was declining slowly. The effective minimum agent amount should not less than 7kg/m^2 to form the barrier.

The jetting effect test of the AES system showed that the speed of forming the barrier was 0.024m/. The roadway barrier type 4×2 (three tubes) is suitable for the section area of 2.75×2.75m^2. And, the roadway barrier type 6×4 (two tubes) is suitable for the 4.2×3.2m^2 section area.

The ES agent amount for the unit area can be calculated by the equivalent: Q'=Q/V=$7\times K_1\times K_2L$

The jetting rate can achieve 90% which is satisfied for the requirement.

The research team analyzed the jetting performance, jetting effect and the jetting rate of the AES system and got the technical parameters of the AES system. It had passed the technical examination from the National Mining Safety Center. The first 300 CH type AES system had been given the “MA” (mining safety) symbol. It supports greatly both on the technology and the theory for the AES system being employed in the coalmines.

Acknowledgements

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References

[1] Yu Bf., *Coal mine methane disaster prevention and utilization technical manual*. Beijing: Coal industry publishing company; 2005, p. 138-179

[2] Zhang TG., *Comprehensive control technology of coalmine methane*. Beijing: Coal industry publishing company; 2001, p. 21-100

[3] Xue SQ. The research of the automatic explosion suppression technology development. *Mining Safety and Environment Protection* 2010; 37: 74-80

[4] Wang JF, Wu JM, Bai YL. Experimen talResearch on the E ffects of South Africa s' HS Suppress ion System. *Chinese Safety Science Journal* 2010;20: 63-8

[5] Ma L, Louis,Li Sl,Wu Jm,Bai Yl,Wang Jf. An experimental research on HS fireproofing technology based on active explosion inhibition in coal mine. *China Coal* 2010;36: 102-105

[6] Niu DW. Discussion on Promotion and Application Issues of HS Mine Active Restrained Explosion System. *Coal Science and Technology*2009;37:43-6

[7] Xie ZH, Song CY. *Engineering fluid dynamics*. Beijing: Metallurgical industry publishing house; 2007, p. 16-21

[8] Spath H. *Fire and Explosion Suppression*, South Africa: PCT /ZA2005 /000163 . 2008

[9] EN /14373. Explosion suppression system[S].2005

[10] Ferrara G, Benedetto AD, Salzano E, Russo G. CFD analysis of gas explosions vented through relief pipes. *Journal of Hazardous Materials* 2006; 137: 654-65

[11] Lin BQ,Gui XH,Numerical Simulation Research on Flame Transmission in Gas Explosion. *Journal of China University of Mining & Technology* 2002;31:6-9

[12]Wang DW,Du CZ. Experimental Study on Gas Explosion and Propagation in a Test Gallery. *Journal of Mining & Safety Engineering*2009;26:475-480,5

[13] Zhu CJ, Lu ZG, Lin BQ, et al. Effect of variation in gas distribution on explosion propagation characteristics in coal mines. *Mining Science and Technology* 2010; 20: 516-9

[14]Xu JD, Yang GY. Numerical simulation of the barricade encouraging effect in the process of gas explosion propagation. *Journal of China Coal Society*2004;2:53-6

[15]Cai ZQ,Li YH,Cheng FM. Experiment on Gas Explosion and Restricted Explosion in Φ700 mm Pipeline. *Coal Science and Technology*2009;37:32-34,92